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Heavy Metal Absorption in Lasolo Bay using a Composite of Cashew-Based Activated Charcoal and Iron Sand, Southeast Sulawesi, Indonesia

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Abstract

This study used a composite of activated charcoal and iron sand extract to reduce the concentrations of heavy metals (Cu, Ni, Zn, Pb, and Cd) in polluted seawater. The grain size of the composite was varied to 60 mesh, 100 mesh, and 200 mesh, with a ratio of activated charcoal to iron sand of 2:3 to optimize absorption. The composite was then compacted into pellets with compaction pressures of 42.2 Pa, 84.8 Pa, and 141.5 Pa, respectively, to achieve optimum compressive strength. The concentrations of heavy metals were measured using an Atomic Absorption Spectrophotometer (AAS). The optimal compaction pressure for the composite was found to be 141.5 Pa, with absorption efficiencies of 61% for Zn, 96% for Pb, 48% for Cd, 90% for Cu, and 94% for Ni. According to the research results, the highest absorption was obtained in composites with a grain size of 200 mesh, with absorption efficiencies of 62.21% for Zn, 96.87% for Pb, 48.14% for Cd, 90.98% for Cu, and 94.15% for Ni. The greater the compaction pressure exerted on the composite, the higher the absorption percentage of the composite pellets. Conversely, a finer grain size also contributes to higher absorption.

Keywords: Cashew Activated Charcoal, Composites, Iron Sand, Heavy Metals, Lasolo Bay

1. Introduction

Lasolo Bay is located in North Konawe Regency, Southeast Sulawesi Province, and is a Marine and Natural Heritage Park conservation area with a depth of approximately 15 meters. In the land area surrounding Lasolo Beach, nickel mining activities are conducted, resulting in pollution through river flows and other water bodies that carry waste containing various contaminants toxic to coastal waters, including the heavy metals Pb, Cd, Cu, Zn, and Ni (Ahmad, 2013). The aquatic chemical and physical properties strongly correlate with the composition and abundance of phytoplankton, which in turn affect the ability of aquatic ecosystems to produce energy (Irawati et al., 2022). Changes in the physical and chemical properties of seawater and the reduction of phytoplankton in the bay area have forced local fishing communities to travel farther to find fish. Heavy metals accumulate in living matter within the food chain. While some heavy metals are required in small amounts to maintain the body's metabolism, they can become harmful above certain levels. At elevated concentrations, these metals become water-soluble and persist in the environment. They cannot be degraded or easily detoxified biologically, which adversely affects the health of plants, animals, and humans (Sahlabji et al., 2022). Cumulative toxins can cause brain problems and cancer if found above tolerance levels (Karasakal and Talib, 2022).

Many researchers have provided alternatives to overcome heavy metal pollution, such as using activated charcoal from chocolate fruit peel (Theobroma cacao L.) as an adsorbent for the heavy metal Cd (II) in aqueous solutions (Handayani and Fauzan, 2021), using seaweed adsorbent to extract Pb metal (Hemavathi et al., 2023), using mangosteen peel as an adsorbent to remove Cr metal (Huang et al., 2013) and the other composites. This study focuses on a composite adsorbent synthesized from iron sand and cashew nut shells. The aim is to develop materials with optimal surface properties, such as silica gel, activated clay, geopolymer, and activated carbon. The composites must exhibit high mechanical strength (Adetunji et al., 2022), with interfacial bond quality (compatibility) improving as the elastic modulus increases, as determined by mechanical testing (Anugraha and Widyastuti, 2014). Cashew nut shells (Anacardium occidentale L.) are a promising non-timber forest biomass waste material for producing activated carbon (Alimah, 2021). Activated charcoal typically contains 85–95% carbon (Chimi et al., 2022), synthesized through carbonization at 500–1000°C (Desi et al., 2015). This process converts the shells into a black residue (charcoal or biochar) (Saenab et al., 2016), which is then activated via high-temperature treatment (Sembiring and Sinaga, 2003) or chemical methods to open pores (Bergna et al., 2020) and enhance adsorption capacity (Bakhri et al., 2021).

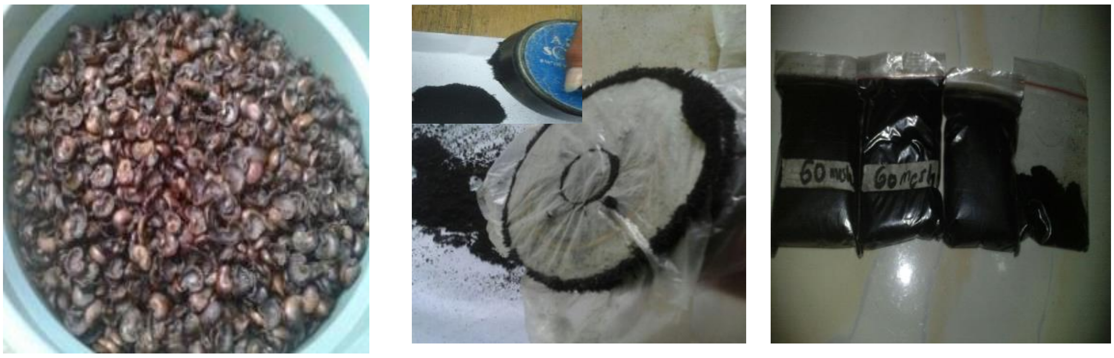
Activated carbon, when applied as an adsorbent (Hussaini Jagaba et al., 2019), also shows significant potential as a strategy in wastewater treatment processes, particularly for solving sludge removal problems and improving cost efficiency (Kumar et al., 2011). While conventional activated carbon derived from wood or coal remains expensive (Quan et al., 2022), the use of activated biocarbon, particularly biochar produced from lignocellulosic biomass, offers a sustainable and low-cost alternative. This material exhibits high adsorption efficiency for both dyes and heavy metals, making it highly effective for treating industrial effluents and removing contaminants from wastewater (Hoang et al., 2022). In addition to its environmental applications, activated biocarbon also plays a crucial role in the development of conductive composite materials because of its excellent electrical conductivity properties. Its effectiveness in eliminating dyes from color effluents (Baloo et al., 2021) and its high capacity for adsorbing heavy metals (Tangjuank et al., 2009) are especially important, considering the increasing industrial use of heavy metals and their growing presence in natural water sources (Karnib et al., 2014).

Iron sand, with unique characteristics, such as a high surface to volume ratio, excellent magnetic and dielectric properties (Mashuri et al., 2018), good biocompatibility, and high absorption capacity (Safitri et al., 2021), is a naturally abundant material in Indonesia (Rianna et al., 2018). Its primary components include iron oxide, titania, silica, and alumina (Gunanto et al., 2018). Due to its strong magnetic properties (Mashuri et al., 2023), iron sand is highly effective as an adsorbent for metal ions, particularly because its surface can be modified to enhance its metal adsorption capacity (Rettob, 2019). We will prepare a composite material by combining activated carbon derived from cashew nut shells with iron sand. The composite will be optimized by applying compaction pressure to achieve the best elastic modulus. To enhance heavy metal adsorption, this study will investigate the effect of varying grain sizes of cashew nut shell carbon and iron sand on the pore structure of the resulting composite pellets. The primary objective is to improve the quality and adsorption performance of the composite materials in effectively removing heavy metal contaminants from aqueous solutions.

2. Materials and Methods

2.1. Sample Preparation

The preparation of the composite material from cashew nut shells and iron sand involved several stages. First, the cashew nut shells were thoroughly cleaned, rinsed with distilled water, and sun-dried for 24 hours to remove impurities and reduce moisture content. They were then heated in a frying pan at approximately 170°C to remove the natural oil varnish. Following this, the shells underwent carbonization at a constant temperature of 400°C. The resulting carbonized material was pulverized using a mortar, then sieved through 60 mesh, 100 mesh, and 200 mesh filters. The sieved samples were placed in petri dishes and activated in an electric furnace at 700°C for 30 minutes. For the iron sand, samples were first washed with distilled water and sun-dried. Magnetic extraction was performed using a permanent magnet wrapped in paper to isolate the magnetic fraction. The extracted sand was then cleaned with alcohol and ground using a mortar. Each sample was sieved using a 60 mesh and stored separately. Activated carbon from cashew nut shells and iron sand of matching grain sizes (60 mesh, 100 mesh, and 200 mesh) were then mixed in a 3:2 ratio using a homogenizer for 15 minutes to ensure uniform blending. The resulting composite samples were categorized by their respective grain sizes. The process of sample screening and preparation is illustrated in **Figure 1.**



(a) Cashew Nut (b) Iron Sand (c) Composite Samples

Figure 1. Preparation Sample Processes: (a) Raw Material of Cashew Nut; (b) Magnetic Extraction of Irond sand; and (c) Composite Samples.

2.2. Bulk Composite Manufacturing Process

A composite sample consisting of 5 grams of activated carbon derived from cashew nut shells and iron sand extract, both with a particle size of 60 mesh, was introduced into a 500 mL Erlenmeyer flask containing seawater. The mixture was agitated using a shaker at a constant speed of 150 rpm for 60 minutes to facilitate adsorption. After stirring, the suspension was filtered using filter paper to separate the solid composite from the aqueous phase. The resulting filtrate was then analyzed for heavy metal content using an Atomic Absorption Spectrophotometer (AAS). The same procedure was repeated for composite samples with particle sizes of 100 mesh and 200 mesh to evaluate the influence of grain size on adsorption performance. The screening and preparation process of the bulk composite sample is illustrated in **Figure 2.** This procedure was repeated for composite samples with grain sizes of 100 mesh and 200 mesh.

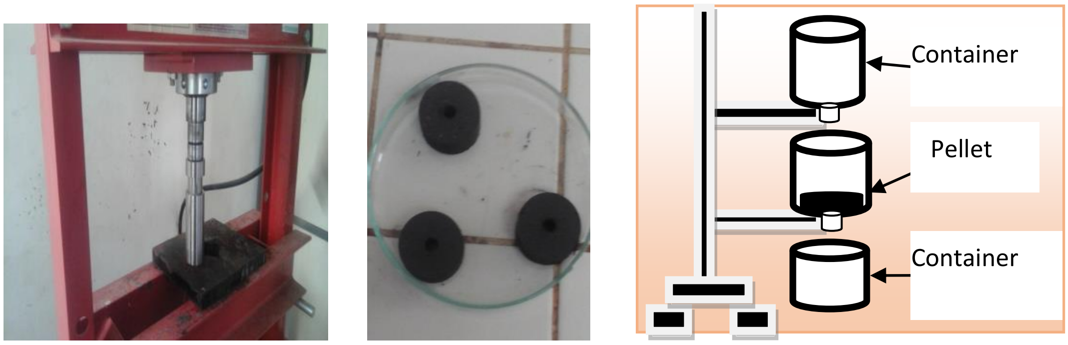
(a) Seawater and Composite (b) Magnetic Stirrer (c) Filtering Samples

Figure 2. Filtering Processes using Bulk Composite: (a) Mixture of seawater and bulk composite; (b) The mixture on magnetic stirrer; and (c) sea water after filtering.

2.3. Pellet Composite Manufacturing Process

In the next stage, the composite sample of cashew nut shell activated carbon and iron sand extract was mixed with a starch-based adhesive and inserted into a cylindrical mold with a height of 10 cm and a cross-sectional area of 3 cm^2. The mixture was then compacted using a hydraulic press at three different pressures: 42.4 Pa, 84.8 Pa, and 141.5 Pa. This compaction process produced pellets weighing 10 grams each, intended to function as adsorbents for heavy metal removal from water samples. Subsequently, 500 mL of seawater was passed through each pellet composite, which served as the filter medium.

The effluent water was then analyzed for heavy metal concentrations using an Atomic Absorption Spectrophotometer (AAS). The pellet composite preparation and screening process is illustrated in **Figure 3.**



(a) Compaction Pressure (b) Pellet Composite (c) Filtering Processes

Figure 3. Filtering Processes using Pellet Composite: (a) The mixture compacted by a hydraulic press; (b) sample pellet composite; and (c) filtering processes.

3. Results and Discussion

Greater attention was given to collecting seawater samples from areas slightly farther offshore to ensure more representative testing conditions for heavy metal removal using the composite. This approach was necessary because coastal seawater near the sampling site had already turned brownish-red due to contamination from mining waste discharged into the sea. The initial concentrations of heavy metals in the collected seawater were measured and compared against the permissible limits established by the Indonesian National Standards (SNI). The results of this comparison are presented in **Figure 4.**

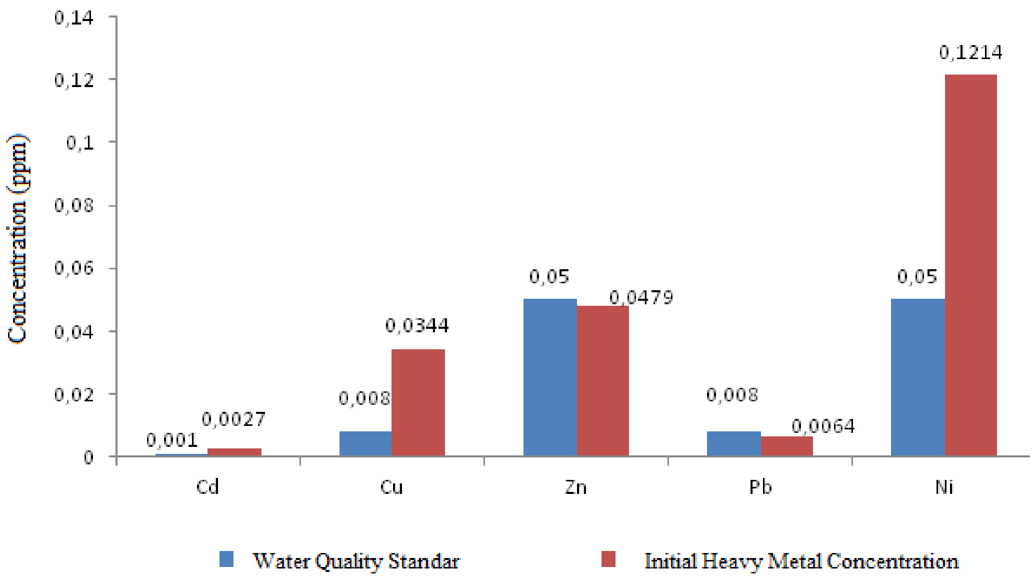


Figure 4. Comparison of Heavy Metal Concentrations in Seawater with Indonesian National Water Quality Standards (SNI).

The absorbency of heavy metals using bulk composites made from activated cashew nut shell charcoal and iron sand extract with varying grain sizes is presented in **Table 1**. The data show a consistent decrease in heavy metal concentrations across all grain sizes. Notably, the smaller the grain size of the composite, the greater the reduction in heavy metal concentration, indicating an increased adsorption capacity. This suggests that finer composite particles provide a larger surface area, enhancing their effectiveness in heavy metal removal.

Table 1. Heavy metal absorbency using bulk composites of activated cashew nut shell charcoal and iron sand with varying grain sizes.

Heavy Metal	Initial concentration (ppm)	Sea water standards	Concentration after Filtering (ppm)		
			60 mesh	100 mesh	200 mesh
Zn	0.0479	0.05	0.0201	0.0198	0.0181
Pb	0.0064	0.008	0.0017	0.0012	0.0002
CDs	0.0027	0.001	0.0023	0.0018	0.0014
Cu	0.0344	0.008	0.0250	0.0125	0.0031
Ni	0.1214	0.05	0.0714	0.0286	0.0071

The percentage of absorption capacity and grain size of the actived cashew charcoal composite and iron sand extract for heavy metals presented in equation 1.

$$\text{Percentage (\%)} = \frac{Initial\ concentration - filtering\ concentration}{initial\ concentration} x100\% \quad (1)$$

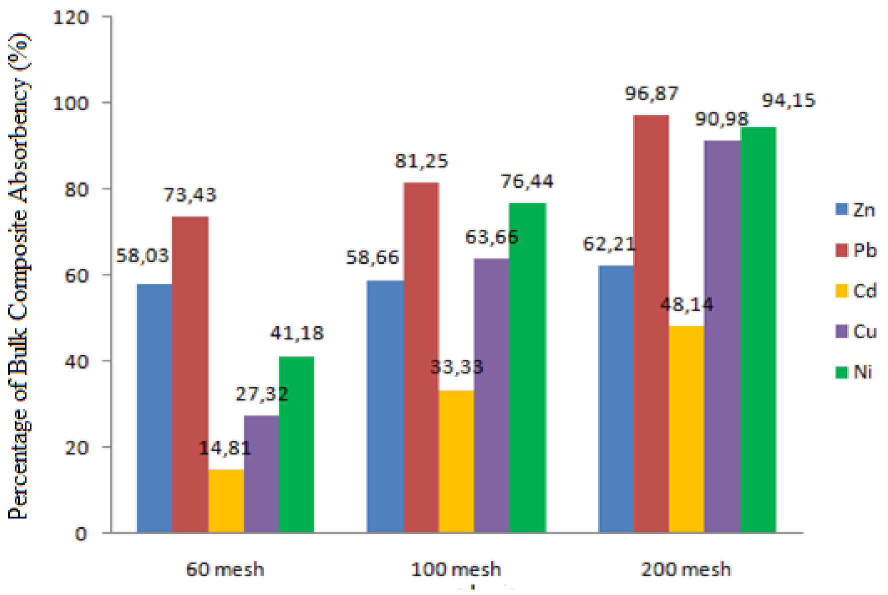


Figure 5. Percentage of Absorbency of Heavy Metals with Variation in Bulk Composite Grain Size.

The absorption percentage of the composite made from activated cashew nut shell charcoal and iron sand extract increased with decreasing grain size, from 60 mesh to 100 mesh, and further to 200 mesh (**Figure 5**). At the finest grain size (200 mesh), the maximum absorption percentages achieved were 62.21% for Zn, 96.87% for Pb, 48.14% for Cd, 90.98% for Cu, and 94.15% for Ni. These results clearly indicate that smaller grain sizes enhance the adsorption efficiency of the bulk composite, likely due to the increased surface area available for interaction with heavy metals. In addition, the adsorption heavy metal of pelletized composites, also made from activated cashew nut charcoal and iron sand, under varying compaction pressures is presented in **Table 2.**

Table 2. Heavy metal absorbency of pellet composites made from activated cashew nut shell charcoal and iron sand at varying compaction pressures.

Heavy Metals	Initial Heavy Metals Concentration (ppm)	Sea water quality standards	Compaction Pressure (Pa)		
			42.4	84.8	141.5
Zn	0.0479	0.05	0.00237	0.0195	0.0184
Pb	0.0064	0.008	0.0021	0.0005	0.0002
CD	0.0027	0.001	0.0021	0.0016	0.0014
Cu	0.0344	0.008	0.0188	0.0063	0.0031
Ni	0.1214	0.05	0.0357	0.0143	0.0071

The relationship between variations in compaction pressure on the composite and the percentage of adsorbed metals for heavy metals Cu, Ni, Pb, Cd, and Zn (**Figure 6)**. The results indicate that as the compaction pressure on the adsorbent pellets increases, the percentage of metal absorption by the pellets also increases for each heavy metal.

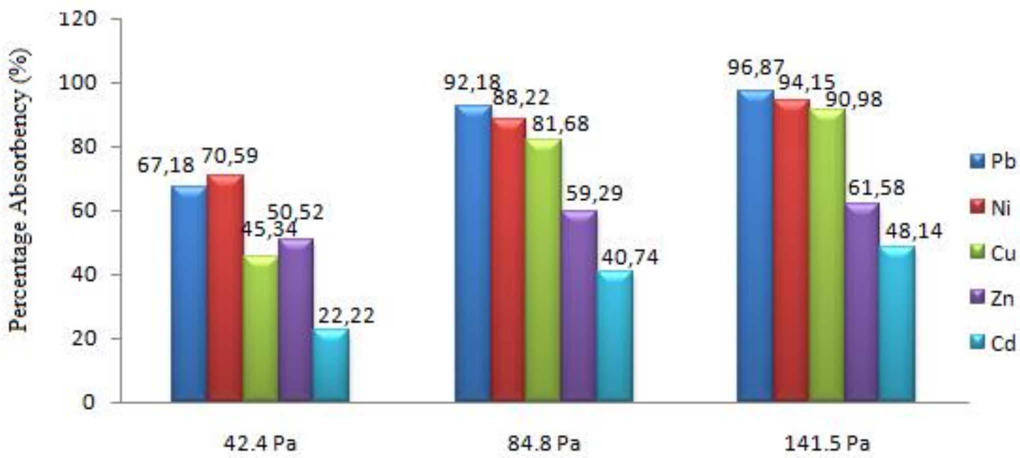


Figure 6. Percentage Absorbency of Heavy Metals by Pellet Composites under Varying Compaction Pressures

3.1. Discussion

This study investigated the effectiveness of filtration media composed of activated charcoal from cashew nut shells and iron sand, focusing on variations in compaction pressure and grain size for heavy metal adsorption. Prior to filtration, the concentrations of heavy metals in seawater samples from Lasolo Bay, North Konawe Regency, were measured as follows: Cu at 0.0344 ppm, Ni at 0.1213 ppm, Zn at 0.0479 ppm, Pb at 0.0064 ppm, and Cd at 0.0027 ppm. According to the Indonesian National Standard (SNI) for seawater quality, the concentrations of Pb and Zn were within acceptable limits. However, the levels of Cu, Ni, and Cd exceeded the permissible thresholds, indicating the need for effective remediation strategies.

The filtering tools using bulk composite show that the maximum absorption of heavy metals occurs with a composite grain size of 200 mesh. The smaller the composite grain size, the greater the percentage of heavy metals absorbed. This finding aligns with the study conducted by Wahab et al. (2023), which reported that cashew charcoal with an optimal grain size of 200 mesh exhibited the highest Pb adsorption efficiency. This enhancement is attributed to the increased surface area, which provides more active sites for metal ion binding. As the grain size decreases, the concentration of heavy metals in solution also declines, due to the improved adsorptive performance of finer particles. The adsorption process of metal ions by the composite will continue until the solution reaches saturation, a state where it cannot absorb any more heavy metal molecules. Additionally, Pb, Cu, Zn and

Ni have higher absorption percentages, while Cd is absorbed less effectively. This indicates that not all heavy metals can be optimally absorbed by the composite of activated cashew charcoal and iron sand. This metal-specific adsorption behavior is consistent with the findings of Kurniawan et al. (2012), who reported removal efficiencies of 89–94% for Pb, Cu, Zn, and Ni, and 52% for Cd using iron-sand composites. Cadmium (Cd) exhibits high viscosity and substantial solubility in water, requiring a longer contact time for optimal adsorption. This is consistent with findings by Fu and Wang (2011), which state that the adsorption of Cd^{2+} is often slower than that of other heavy metals due to its high hydration energy and solubility, both of which hinder its interaction with adsorbent surfaces and extend the time needed to reach equilibrium. In contrast, Pb, Cu, Zn, and Ni are absorbed more effectively due to their flexible and magnetic properties, which strongly associate with Iron sand. In this context, adsorption occurs through several mechanisms. The pore size of the adsorbent is larger than the size of the ion being adsorbed, and ion exchange can be influenced by the electronegativity value of the adsorbent.

Furthermore, heavy metal adsorption was also evaluated using pellet composites made from activated cashew nut shell charcoal and iron sand extract, with compaction pressures of 42.4 Pa, 84.8 Pa, and 141.5 Pa. This variation aimed to assess and determine the optimal compaction pressure for maximum adsorption efficiency. The results indicate that the compaction pressure applied during the pellet formation process significantly influences the adsorption capacity of the composite. As shown in **Figure 6**, the highest percentages of heavy metal absorption for Cu, Ni, Zn, Pb, and Cd were achieved at a compaction pressure of 141.5 Pa. The findings suggest that increasing compaction pressure enhances the structural integrity of the pellets, resulting in higher adsorption efficiency. This is primarily attributed to the changes in pore structure caused by compaction. Pressure affects the pore size and surface area of the composite adsorbent, which are critical factors in adsorption. The optimization thresholds align with the findings of Chen et al. (2022), identifying 5–15 MPa as the optimal compaction range for shales, which effectively balances structural integrity and permeability. Higher compaction pressures tend to reduce pore size while increasing particle contact density, potentially enhancing the interactions between the adsorbent and heavy metal ions. However, excessive compaction can lead to a denser structure, potentially restricting fluid flow through the composite and thereby reducing its overall adsorption performance. Therefore, optimizing compaction pressure is essential to balancing pore accessibility and structural integrity for effective heavy metal removal.

The highest adsorption percentages of Pb, Ni, Zn, and Cu, compared to the relatively low adsorption of Cd, are influenced by factors such as the adsorbent's surface properties, solution viscosity, and metal solubility. Cadmium (Cd^{2+}) exhibits high solubility and low adsorption affinity in aqueous systems due to its ionic mobility, requiring extended contact times for optimal uptake. The composite of iron sand and cashew nut shell-activated charcoal demonstrates superior adsorption efficiency compared to conventional adsorbents. This synergy enhances the surface area and the number of active sites, facilitating the effective binding of larger metal ions such as Pb^{2+} and Cu^{2+}. The pore structure modification, characterized by a 24.3–69.2% reduction in macropores under compaction, correlates with improved Pb^{2+} adsorption efficiency (Zhang et al., 2020). Using composite adsorbents like activated cashew nut shell charcoal and iron sand offers significant environmental benefits by converting agricultural and natural waste into valuable materials, reducing carbon footprint, promoting biodegradability, enabling effective heavy metal removal, supporting local resource utilization, minimizing secondary pollution, and aligning with circular economy principles through reuse and regeneration.

4. Conclusions

The analysis of the absorbency performance of composite materials made from activated cashew nut shell charcoal and iron sand in both pellet and bulk forms has been successfully conducted using seawater samples from Lasolo Bay. The optimal compaction pressure for pellet composites was identified at 141.5 Pa, achieving absorption efficiencies of 61% for Zn, 96% for Pb, 48% for Cd, 90% for Cu, and 94% for Ni. Similarly, the highest absorbency in bulk composites was recorded with a grain size of 200 mesh, yielding absorption efficiencies of 62.21% for Zn, 96.87% for Pb, 48.14% for Cd, 90.98% for Cu, and 94.15% for Ni. The study concluded that increased compaction pressure and smaller grain sizes significantly enhance heavy metal adsorption due to improved surface area and pore structure. Moreover, pellet composites proved to be more practical and efficient than bulk forms in application. Therefore, for effective removal of hazardous heavy metals from seawater, the use of pellet composites with a compaction pressure of 141.5 Pa and a grain size of 200 mesh is strongly recommended.

Conflicts of Interest

There are no conflicts to declare.

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